# CS4220
# Computer Networks

## Lecture 1 Introduction

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## Introduction

- **Uses of Computer Networks**
- **Network Hardware**
- **Network Software**
- **Reference Models**
- **Example Networks**
- **Network Standardization**
- **Metric Units**

## Uses of Computer Networks

**Computer networks are collections of autonomous computers and facilities, e.g., the Internet**

**They have many uses:**

- **Business Applications »**
- **Home Applications »**
- **Mobile Users »**

**These uses raise:**

- **Social Issues »**

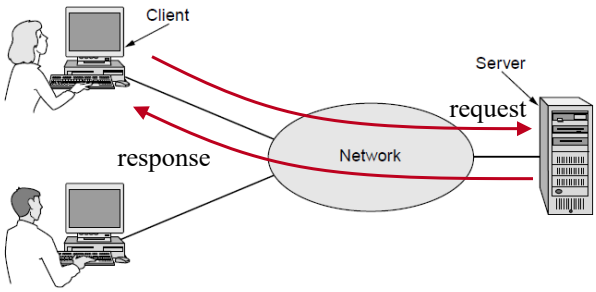
° **This text covers networks for all of these uses**





## Client/Server Model - Functionality

° **Companies use networks and computers for resource sharing with the client-server model:**



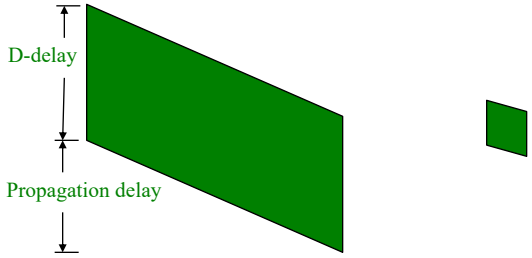

° **Other popular uses are communication, e.g., email, VoIP, and e-commerce**

° **How about Reliability?**

## Client/Server Model - Performance

° The performance of a client-server system is influenced by two factors: the bandwidth of the network (how many bits/sec it can transport) and the propagation latency (how much time it takes for the first bit to get from the client to the server).

Please give an example of a network that exhibits high bandwidth and high latency. Then give an example of one with low bandwidth and low propagation latency.




Propagation delay is independent to the bandwidth, but the distance.



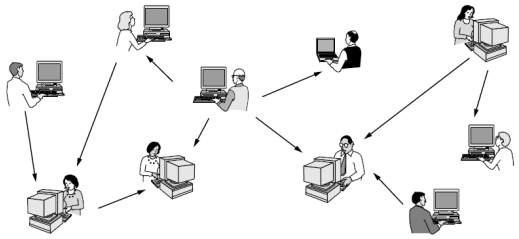


## Home Network Applications

° Homes contain many networked devices, e.g., computers, TVs, connected to the Internet by cable, DSL, wireless, etc.

° Home users communicate, e.g., social networks, consume content, e.g., video, and transact, e.g., auctions

° Some application use the peer-to-peer model in which there are no fixed clients and servers:



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## Services & Applications

- **Service: Basic information transfer capability**
  - Internet transfer of individual block of information
  - Internet reliable transfer of a stream of bytes
  - Real-time transfer of a voice signal
- **Applications build on communication services**
  - E-mail & web build on reliable stream service
  - Fax and modems build on basic telephone service
- **New applications build on multiple networks**
  - SMS (short message service) builds on Internet reliable stream service and cellular telephone text messaging



## Mobile Network Users

- **Combinations of wireless networks and mobile computing.**
  - Tablets, laptops, and smart phones are popular devices; WiFi hotspots and cellular provide wireless connectivity.
  - Wireless and mobile are related but different:

| Wireless | Mobile | Applications |
|---|---|---|
| No | No | Desktop computers in offices |
| No | Yes | A notebook computer used in a hotel room |
| Yes | No | Networks in older, unwired buildings |
| Yes | Yes | Portable office; PDA for store inventory |

## Social Issues

- **Network neutrality – no network restrictions**
- **Content ownership, e.g., DMCA takedowns**
  - **Digital Millennium Copyright Act**.
  - When **content is removed from a website** at the request of the owner of the content or the owner of the copyright of the content. It is a well-established Internet standard.
- **Anonymity and censorship**
- **Privacy, e.g., Web tracking and profiling**
- **Theft, e.g., botnets and phishing**





## Network Hardware

- **Networks can be classified by their scale:**

| Scale | Type |
|---|---|
| Vicinity | PAN (Personal Area Network) » |
| Building | LAN (Local Area Network) » |
| City | MAN (Metropolitan Area Network) » |
| Country | WAN (Wide Area Network) » |
| Planet | The Internet (network of all networks) |

**Classifications: Size, transmission technology, and topology**

## Transmission Technology Classification

- Two Types of transmission technology
  - Broadcast links
  - Point-to-point links
- Broadcast Networks have a single communication channel that is shared by all the machines on the network
  - Can a broadcast network support 1-1, 1-many communications? And How?
- Point-to-point networks consist of many connections between individual pairs of machines
  - Can a point-to-point network support 1-many and 1-all communications? And how?

General rule: smaller and geographically localized networks tend to use broadcasting while larger networks usually are point-to-point.





## Scale Classification

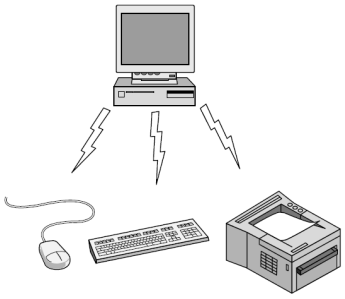
- Classification of networks by scale.

| Interprocessor distance | Processors located in same | Example |
|---|---|---|
| 1 m | Square meter | Personal area network |
| 10 m | Room | Local area network |
| 100 m | Building | |
| 1 km | Campus | |
| 10 km | City | Metropolitan area network |
| 100 km | Country | Wide area network |
| 1000 km | Continent | |
| 10,000 km | Planet | The Internet |

## Personal Area Network

**Connect devices over the range of a person**

**Example of a Bluetooth (wireless) PAN:**



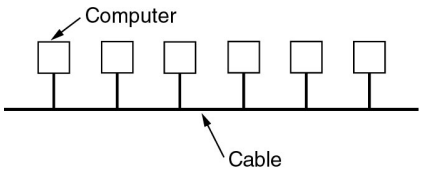


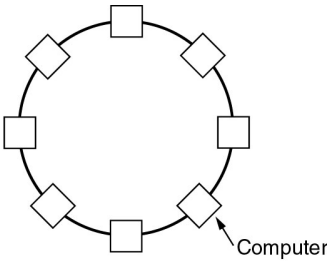


## Local Area Networks (LAN)

- **LANs are privately-owned networks within a single building or campus of up to a few KMs in size.**
- **How LANs are distinguished from other networks?**
  - **Size**
  - **Transmission technology**
  - **topology**

**How to arbitrate?**



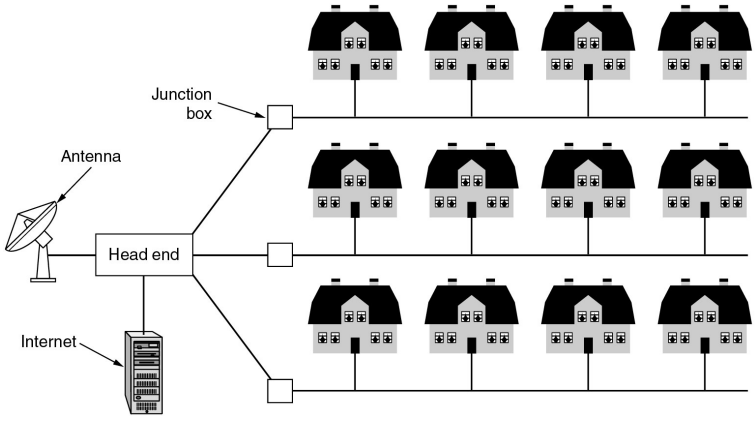




**Two broadcast networks (a) Bus-based, (b) Ring**

**What is the benefit from the restricted network size?**

## Metropolitan Area Networks (MAN)

- Connect devices over a metropolitan area
- A metropolitan area network based on cable TV.

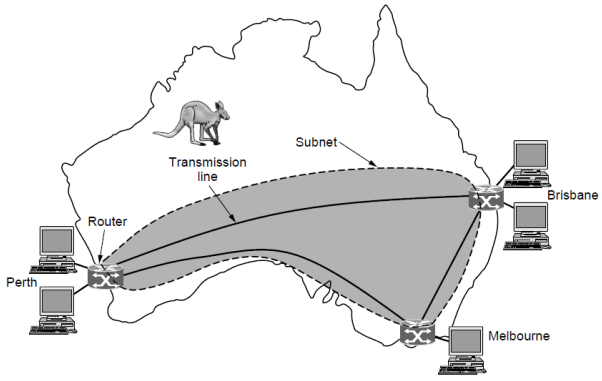






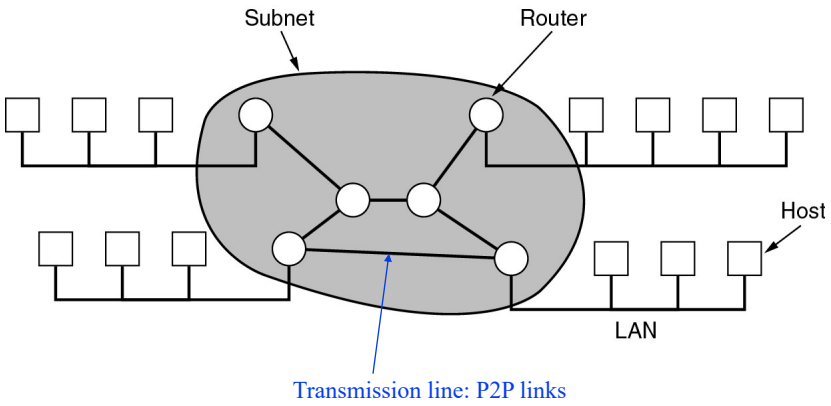

## Wide Area Networks (1)

- Connect devices over a country/continent
- Example WAN connecting three branch offices. WANs VS LANs
  - Owned and operated by different people
  - Connect different kinds of networking technology
  - What is connected to the subnet differs



## Wide Area Networks (2)

- **Relation between hosts on LANs and the subnet.**



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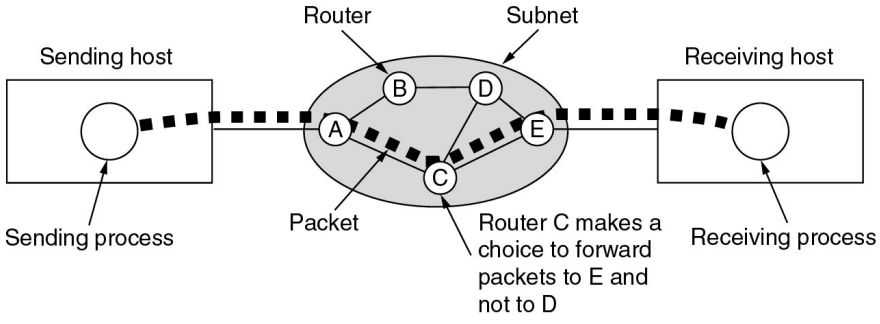
## Wide Area Networks (3)

- **Store-and-forward (packet-switched): a packet is stored in an intermediate router in its entirety, stored there until the required output line is free, and then forwarded.**




**A stream of packets from sender to receiver.**

**Must all packets of a message follow the same route?**



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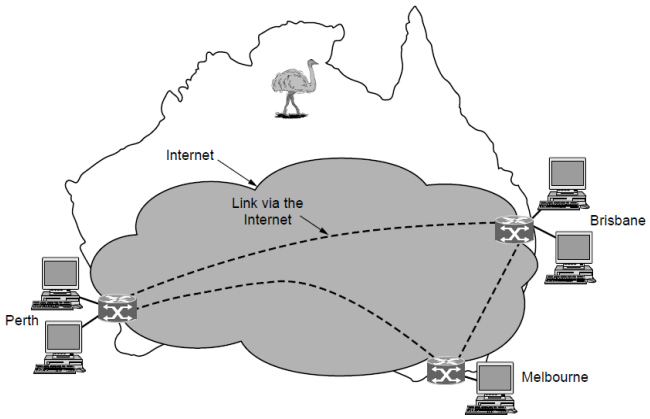
## Wide Area Networks (4)

° A VPN (Virtual Private Network) is a WAN built from virtual links that run on top of the Internet.

- Virtualization leads to flexible use (Internet connectivity)





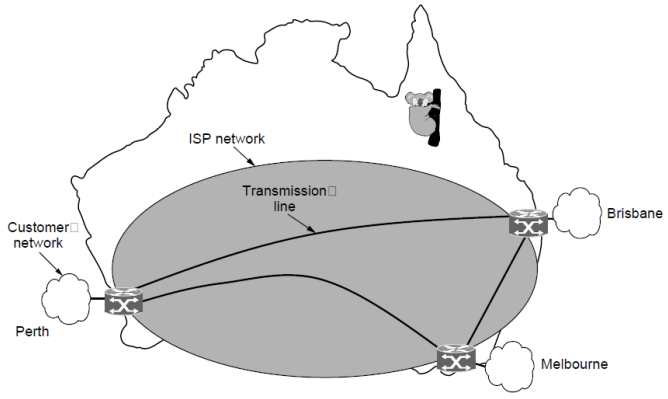





## Wide Area Networks (4)

° An ISP (Internet Service Provider) network is also a WAN.

° Customers buy connectivity from the ISP to use it.



## Wireless Networks

**Three Categories of wireless networks:**

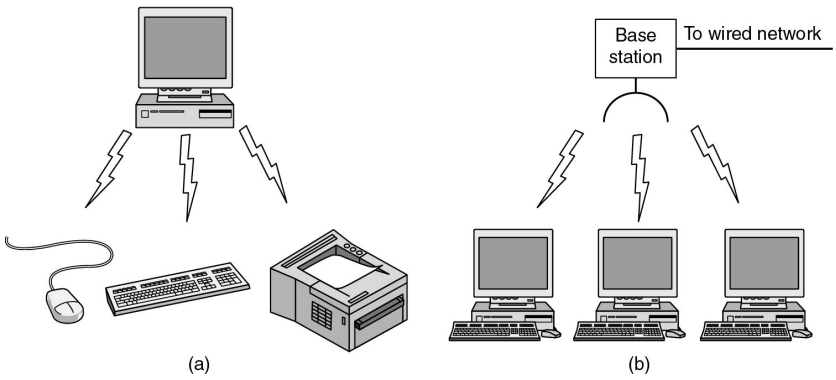
- **System interconnection**
- **Wireless LANs**
- **Wireless WANs**





## Wireless Networks (2)

- **(a) Bluetooth configuration for system interconnection**
- **(b) Wireless LAN (802.11)**



## Wireless Networks (3)

- Wireless WANs
  - The radio network for cell phones (4G/5G)
  - The local multipoint distribution service (802.16)

Bandwidth vs. scope/coverage



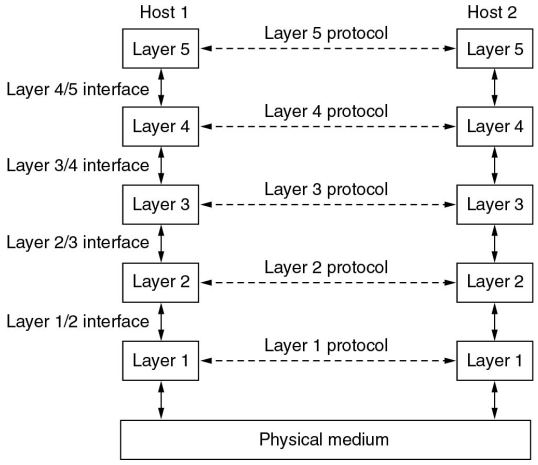


## Network Software

- Protocol Hierarchies
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

## Network Software: Protocol Hierarchies

° **Networks are organized as a stack of layers/levels, each one built upon one below it.**




**Why hierarchical Network architecture?**

**Layers, protocols, and interfaces.**



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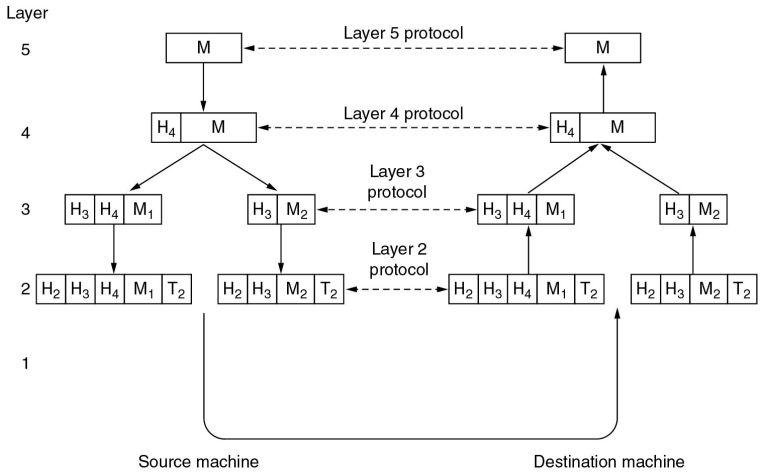
## Protocol Hierarchies (2)

° **The relation between the virtual and actual communication and the difference between protocols and interfaces.**




What is the effective bandwidth utilization?



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## Design Issues for the Layers

- **Addressing**
- **Framing**
- **Error Control**
- **Flow Control**
- **Ordering**
- **Multiplexing**
- **Routing**
- **Congestion control**
- **Quality of Service (QoS)**





## Connection-Oriented and Connectionless Services

- **Layers can offer two different type of services to the layer above them: telephone systems vs. postal systems.**

| | Service | Example |
|---|---|---|
| Connection-oriented | Reliable message stream | Sequence of pages |
| | Reliable byte stream | Remote login |
| | Unreliable connection | Digitized voice |
| Connection-less | Unreliable datagram | Electronic junk mail |
| | Acknowledged datagram | Registered mail |
| | Request-reply | Database query |

Six different types of service.

**What is reliable and unreliable communication? Think about postal services**

**Can a unreliable service be made reliable by using a network software?**

**Why would anyone actually prefer unreliable to reliable communication?**

## Service Primitives

° **A service is specified by a set of primitives (operations) available to a user process to access the service.**

| Primitive | Meaning |
|---|---|
| LISTEN | Block waiting for an incoming connection |
| CONNECT | Establish a connection with a waiting peer |
| RECEIVE | Block waiting for an incoming message |
| SEND | Send a message to the peer |
| DISCONNECT | Terminate a connection |

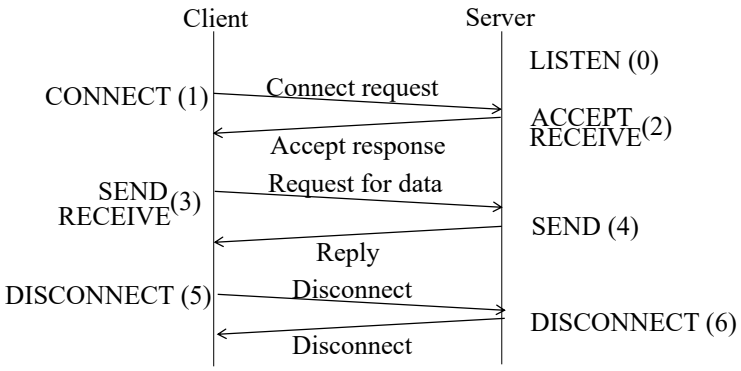
**Five service primitives for implementing a simple connection-oriented service.**





## Service Primitives (2)

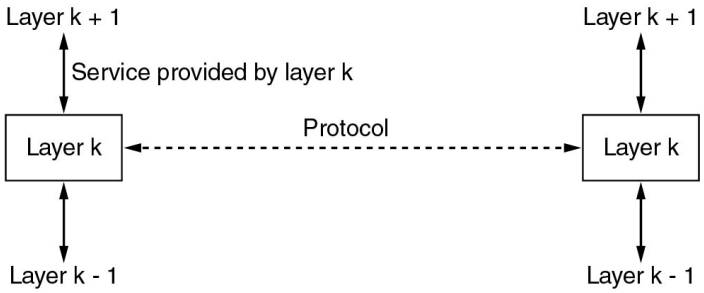
° **Hypothetical example of how these primitives may be used for a client-server interaction**




**Life is not so simple. What could be wrong?**

## Services to Protocols Relationship

- A service is a set of primitives (operations) available to a user process to access the service
- A protocol is a set of rules/agreements governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer (relates to the implementation of a service)




**The relationship between a service and a protocol.**





## Reference Models

- The OSI Reference Model
- The TCP/IP Reference Model
- A Comparison of OSI and TCP/IP
- A Critique of the OSI Model and Protocols
- A Critique of the TCP/IP Reference Model

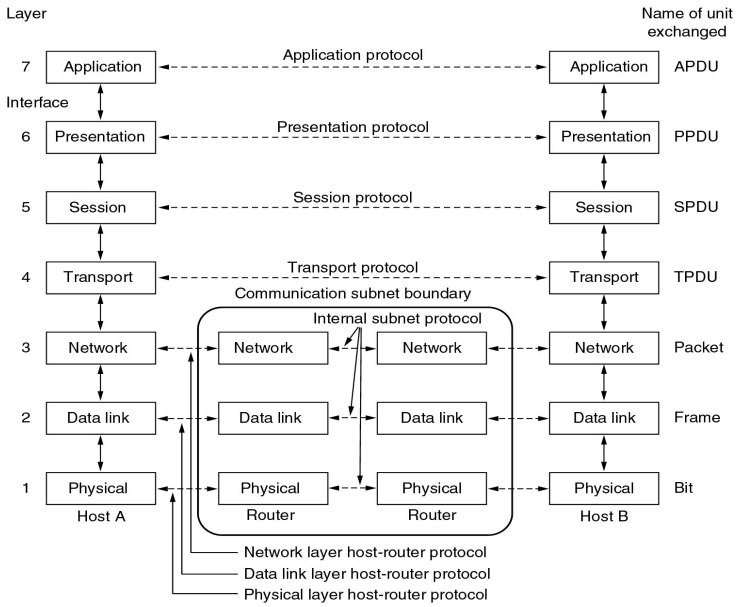
Optimized, but also many alternatives & trade-offs

## Why Layering Architectures?

- Layering simplifies design, implementation, and testing by partitioning overall communications process into parts
  - Information hiding, abstracted data types, data encapsulation
- Protocol in each layer can be designed separately from those in other layers
- Protocol makes "calls" for services from layer below
- Layering provides flexibility for modifying and evolving protocols and services without having to change layers below
- Monolithic non-layered architectures are costly, inflexible, and soon obsolete

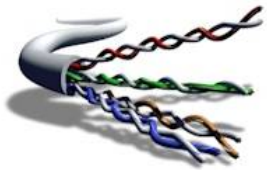


## OSI Reference Model



## Physical Layer

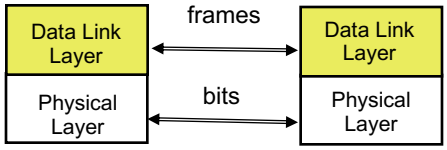
- Transfers bits across link
- Definition & specification of the physical aspects of a communications link
  - Mechanical: cable, plugs, pins...
  - Electrical/optical: modulation, signal strength, voltage levels, bit times, …
  - functional/procedural: how to activate, maintain, and deactivate physical links…
- Ethernet, DSL, cable modem, telephone modems…
- Twisted-pair cable, coaxial cable, optical fiber, radio, …





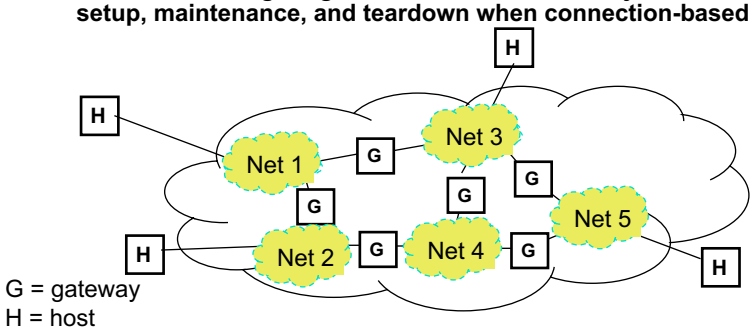
## Data Link Layer

- Transfers *frames* across *direct* connections
  - Groups bits into frames
  - Detection of bit errors; Retransmission of frames
- Activation, maintenance, & deactivation of data link connections
- Medium access control for local area networks
- *Node-to-node* flow control



## Network Layer

- Transfers *packets* across multiple links and/or multiple networks
  - *Addressing* must scale to large networks
  - Nodes jointly execute *routing* algorithm to determine paths across the network
  - *Forwarding* transfers packet across a node
  - *Congestion control* to deal with traffic surges
  - *Others: tunneling, fragmentation and reassembly, Connection* setup, maintenance, and teardown when connection-based



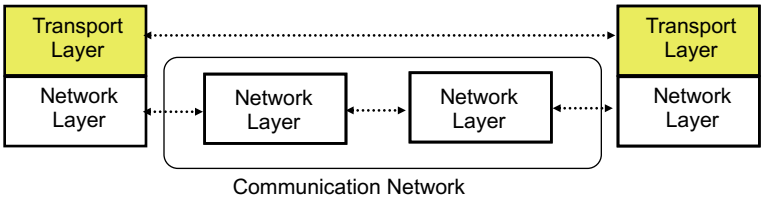

G = gateway
H = host





## Transport Layer

- Transfers data end-to-end from process in a machine to process in another machine
  - *Reliable* stream transfer or quick-and-simple single-block transfer
  - Port numbers for addressing (and multiplexing)
  - Message segmentation and reassembly
  - Connection setup, maintenance, and release
  - End-to-end congestion control vs. node-to-node flow control

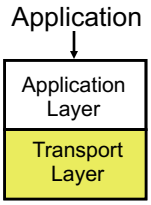



What data link layer and transport layer have in common and differ?

## Application & Upper Layers

- **Application Layer: Provides services that are frequently required by applications: DNS, web access, file transfer, email…**
- **Presentation Layer: machine-independent representation of data…**
- **Session Layer: dialog management, recovery from errors, …**

**Incorporated into Application Layer**



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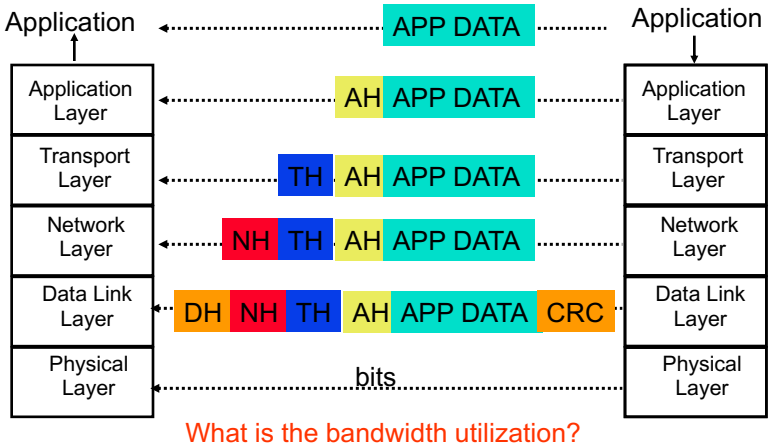
## Headers & Trailers

- **Each protocol uses a header that carries addresses, sequence numbers, flag bits, length indicators, etc…**




What is the bandwidth utilization?



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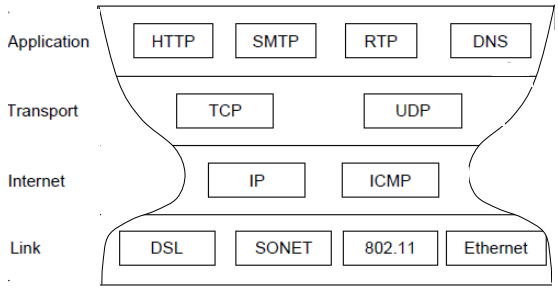
## The TCP/IP Reference Model

° **A four layer model derived from experimentation; omits some OSI layers and uses the IP as the network layer.**




IP is the "narrow waist" of the Internet

Protocols are shown in their respective layers

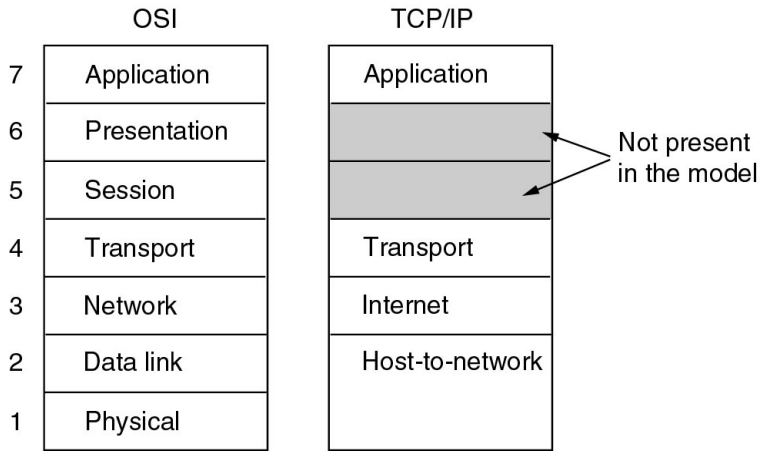






## The TCP/IP Reference Model (2)

° **ARPANET**
- **To connect multiple networks in a seamless way, TCP/IP**
- **To enable networks survive loss of subnet hardware**



## Critique of OSI & TCP/IP

**OSI:**

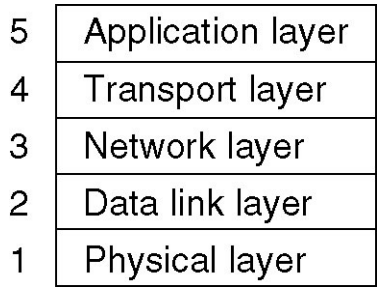
- \+ Very influential model with clear concepts
- \- Models, protocols and adoption all bogged down by politics and complexity
- \- Bad timing

**TCP/IP:**

- \+ Very successful protocols that worked well and thrived
- \- Weak model derived after the fact from protocols
- \- Service, interface, and protocol not distinguished
- \- Not a general model



## The Hybrid Model




**The hybrid reference model to be used in this book.**

## Comparing OSI and TCP/IP Models

Concepts central to the OSI model

- Services
- Interfaces
- Protocols



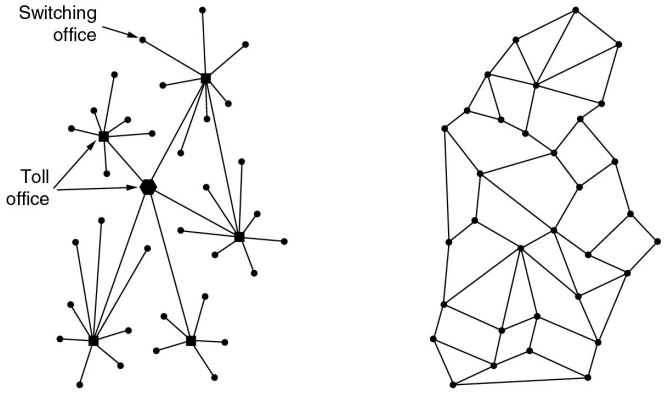


## Example Networks

- The Internet
- 3G mobile phone networks
- Connection-Oriented Networks:
  X.25, Frame Relay, and ATM
- Ethernet
- Wireless LANs: 802.11
- RFID and sensor networks

## The ARPANET

- (a) Structure of the telephone system.
- (b) Baran's proposed distributed switching system.




What is the vulnerability of the telephone system?

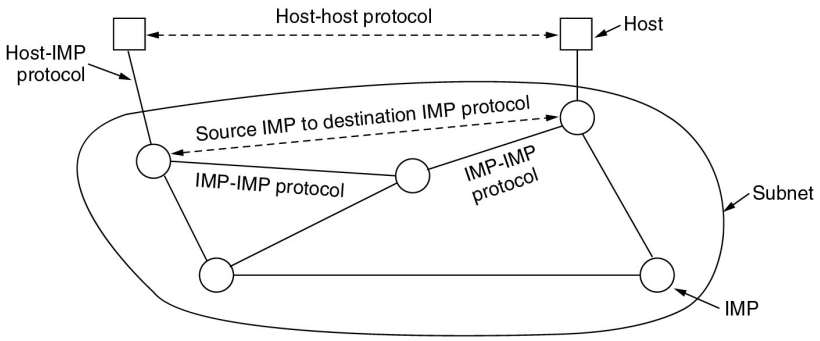
Why the distributed switching system is more reliable?





## The ARPANET (2)

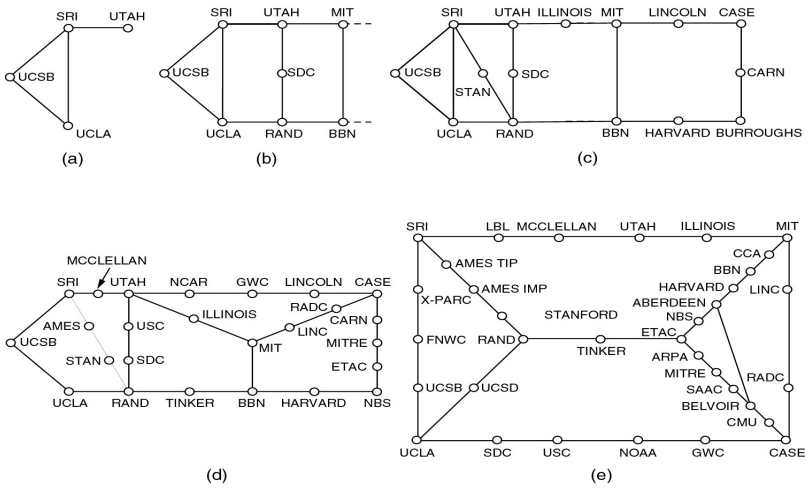
- The subnet consists of minicomputers called IMPs (Interface Message Processors) connected by 56-kbps transmission lines, each connected to at least two other IMPs
  - First store-and-forward switching network




The original ARPANET design.

Why the subnet was to be a datagram subnet?

## The ARPANET (3)



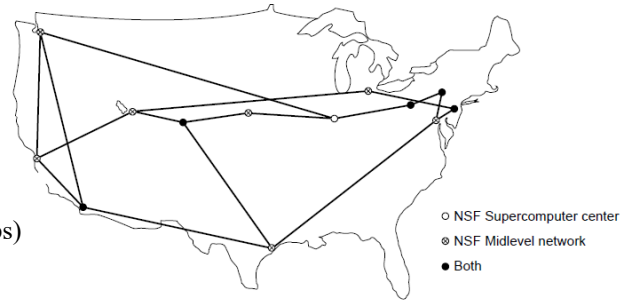

**Growth of the ARPANET (a) December 1969. (b) July 1970. (c) March 1971. (d) April 1972. (e) September 1972.**





## NSFNET

- **The early Internet used NSFNET (1985-1995) as its backbone**
  - **To design a successor to the ARPNET that would be open to all university research groups.**
  - **First TCP/IP WAN**




NSFNET topology in 1988

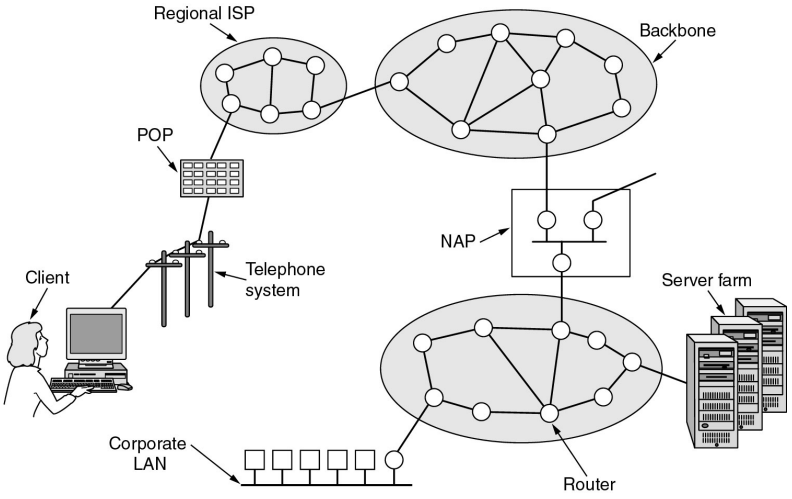
## Modern Internet

- The modern Internet is more complex:
  - ISP networks serve as the Internet backbone
  - ISPs connect or peer to exchange traffic at IXPs
  - Within each network routers switch packets
  - Between networks, traffic exchange is set by business agreements
  - Customers connect at the edge by many means
    - Cable, DSL, Fiber-to-the-Home, 4G/5G wireless, dialup
  - Data centers concentrate many servers ("the cloud")
  - Most traffic is content from data centers (esp. video)
  - The architecture continues to evolve



## Architecture of the Internet

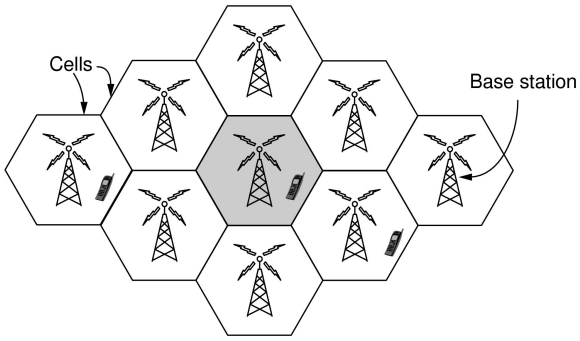
**Overview of the Internet.**




**What are ISPs for? Who are at the top of the food chain?**

## 4G Mobile Phone Networks (1)

- **4G network is based on spatial cells; each cell provides wireless service to mobiles within it via a base station**

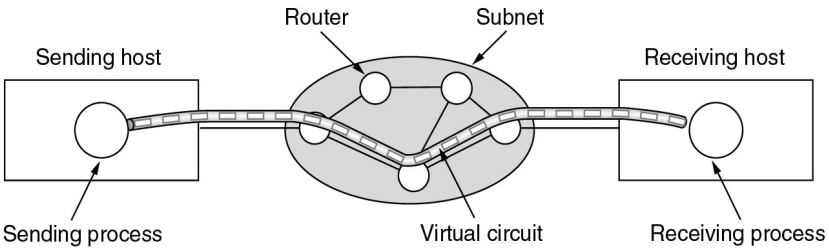




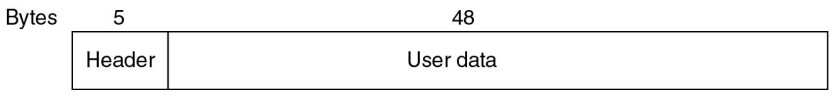



## Connection-Oriented Networks: ATM Virtual Circuits

- **A virtual circuit is a connection with resources reserved.**



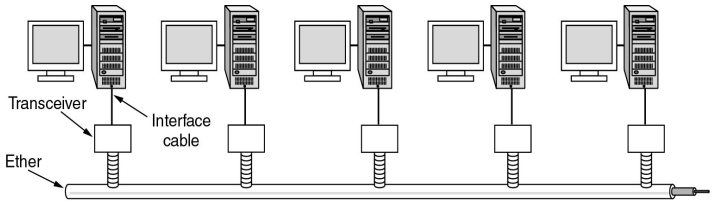

- **A Cell is a small and fixed-size packet, delivered in order.**




**A war: why do the telephone companies like connection-oriented and why ARPANET goes for connectionless instead?**

## LAN: Ethernet

- Architecture of the original (Xerox) Ethernet.




Coaxial cable, a multi-drop cable

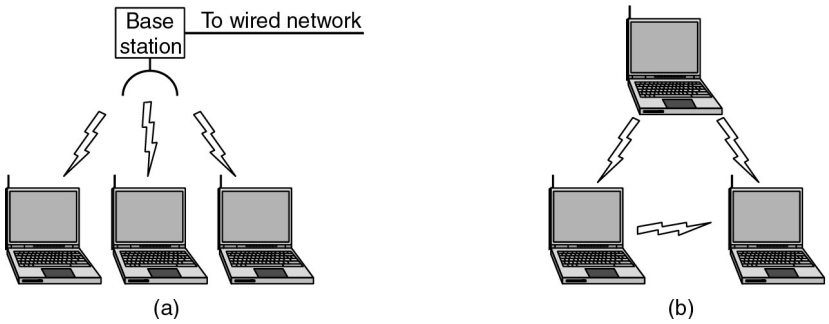
- DIX (DEC, Intel, Xerox) standard in 1978, a 10-Mbps Ethernet
  - Other LAN standards: token bus and token ring
  - Modern Ethernet is switched based with point-to-point links

**In classical Ethernet, what happens if two or more computer all wait until the current transmission completes and then all start at once?**





## Wireless LANs

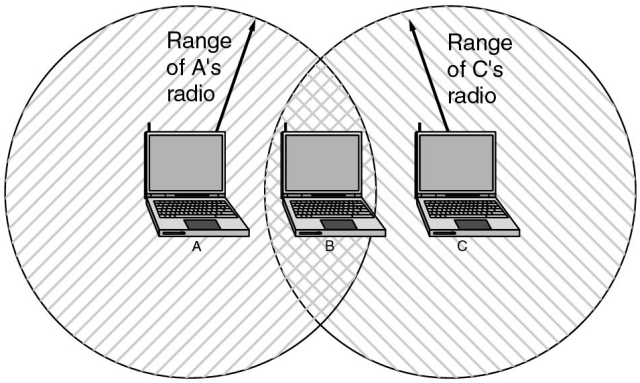



- (a) Wireless networking with a base station (802.11, WiFi).
- (b) Ad hoc networking.

**Compatible with Ethernet at the data link layer: to send an IP packet over the wireless LAN the same way a wired computer sent an IP packet over Ethernet.**

## Wireless LANs (2)

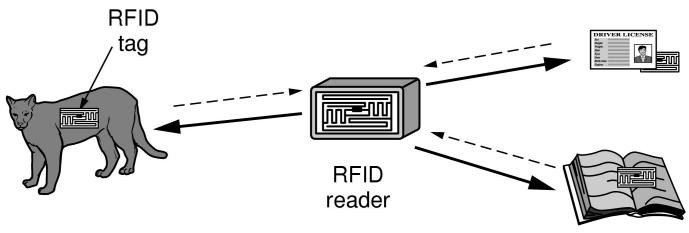
° The range of a single radio may not cover the entire system





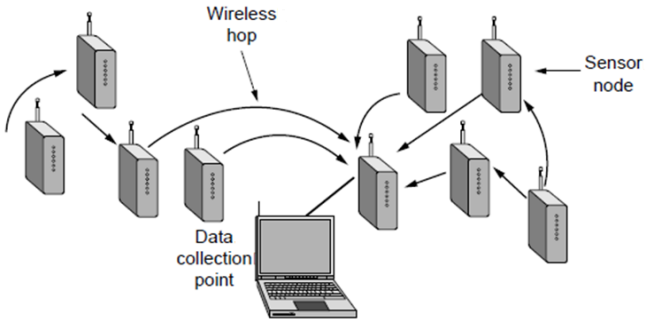

## RFID and Sensor Networks (1)

- **Passive UHF RFID networks everyday objects:**
  - **RFID: Radio Frequency IDentification**
  - **Tags (stickers with not even a battery) are placed on objects**
  - **Readers send signals that the tags reflect to communicate**



## RFID and Sensor Networks (2)

- **Sensor networks spread small devices over an area:**
  - **Devices send sensed data to collector via wireless hops**
  - **Typically with batteries, but energy is a key challenge**
  - **Multi-hop network: relay messages for each other**








## Network Standardization

- **Standards define what is needed for interoperability**
- **Some of the many standards bodies:**

| Body | Area | Examples |
|---|---|---|
| ITU | Telecommunications | G.992, ADSL<br>H.264, MPEG4 |
| IEEE | Communications | 802.3, Ethernet<br>802.11, WiFi |
| IETF | Internet | RFC 2616, HTTP/1.1<br>RFC 1034/1035, DNS |
| W3C | Web | HTML5 standard<br>CSS standard |

## Metric Units

| Exp. | Explicit | Prefix | Exp. | Explicit | Prefix |
|---|---|---|---|---|---|
| $10^{-3}$ | 0.001 | milli | $10^{3}$ | 1,000 | Kilo |
| $10^{-6}$ | 0.000001 | micro | $10^{6}$ | 1,000,000 | Mega |
| $10^{-9}$ | 0.000000001 | nano | $10^{9}$ | 1,000,000,000 | Giga |
| $10^{-12}$ | 0.000000000001 | pico | $10^{12}$ | 1,000,000,000,000 | Tera |
| $10^{-15}$ | 0.000000000000001 | femto | $10^{15}$ | 1,000,000,000,000,000 | Peta |
| $10^{-18}$ | 0.000000000000000001 | atto | $10^{18}$ | 1,000,000,000,000,000,000 | Exa |
| $10^{-21}$ | 0.000000000000000000001 | zepto | $10^{21}$ | 1,000,000,000,000,000,000,000 | Zetta |
| $10^{-24}$ | 0.000000000000000000000001 | yocto | $10^{24}$ | 1,000,000,000,000,000,000,000,000 | Yotta |

Use powers of 10 for rates, powers of 2 for storage
E.g., 1 Mbps = 1,000,000 bps, 1 KB = 1024 bytes
"B" is for bytes, "b" is for bits



## Example

- **An image is 640 X 480 pixels with 2 bytes/pixel. Assume the image is uncompressed. How long does it take to transmit it over a 56-kbps modem channel? Over a 1.5 Mbps DSL?**

## Summary: What are communication networks?


- **The equipment (hardware & software) and facilities that provide the basic communication service**
  - **A computer network is a collection of autonomous computers interconnected by a single technology**

- **Equipment**
  - **Routers, servers, switches, multiplexers, hubs, modems, …**

- **Facilities**
  - **Copper wires, coaxial cables, optical fiber**
  - **Ducts, conduits, telephone poles …**

***How are communication networks designed and operated?***





## Reading

- **Chapter 1 of the textbook.**